ON THE EXISTENCE OF EXTERNAL GALAXIES

By Harlow Shapley

I. Introduction

In the present state of astrophysical knowledge, the problem of the existence of external stellar systems similar to our Galaxy reduces almost immediately to the problem of the status of spiral nebulae in the sidereal universe. In treating this question we must deal primarily with the "island-universe" hypothesis of spirals—an interpretation of long standing, which at the present time has many adherents and appears to be growing in general acceptance.[1]

The recent work on star clusters, in so far as it throws some light on the probable extent and structure of the galactic system, justifies a brief reconsideration of the question of external galaxies, and apparently leads to the rejection of the hypothesis that spiral nebulae should be interpreted as separate stellar systems. During the last two or three years a considerable amount of observational material bearing on the problem has come to hand, much of which was either not known or not fully considered by previous writers on the subject.

Four classes of objects, other than spiral and closely associated nebulae, have at times been suggested as possible external galaxies, the first three of which may be dismissed as no longer open to such interpretation: (1) *Large star clouds of the Milky Way:* the affiliation with the galactic region and its characteristic population shows them to be a fundamental part of the galactic system; (2) *The Magellanic Clouds:* the apparent magnitudes of their short-period variable stars determine definitely the order of the distance and size of these detached stellar systems, and prove them to be small in comparison with the galactic system;[2] (3) *Globular clusters:* those so far discovered are recognized now as dependents of the galactic system, altho in many respects they are miniatures of the Galaxy and apparently for the most part are external to the regions where most of the galactic stars are found; (4) *Various peculiar nebulae*

[1]Among special discussions of the theory, three should be mentioned: an article by Puiseux, "Spiral Nebulae," *Revue Scientifique*, April 6, 1912; Crommelin's paper "Are the Spiral Nebulae External Galaxies?" *Scientia*, v. 21, p. 365, 1917 (reprinted in the *Journal of the Royal Astronomical Society of Canada*, v. 12, 33, 1918); and the recent address by Curtis, "Modern Theories of Spiral Nebulae," *Journal of the Washington Academy of Sciences*, v. 9, 217, 1919. In all of these the evidence is held to be favorable to the "island universe" theory. The arguments reviewed and extended by Curtis are so fully and clearly expressed that they may be taken as presenting the case for the stellar interpretation of spiral nebulae. The alternative theory that the spirals are not stellar has been maintained little, if at all, in recent years.

[2]*Mt. Wilson Contr.*, No. 151, pp. 20 and 25, 1917; No. 152, p. 2, 1917.

and nebulous stars: concerning them little is known, but in most cases they are to be classed with the ordinary gaseous nebulae (which are clearly associated with the Milky Way), or with peculiar types of individual stars, or with the faint spirals.

II. Outline of Evidence Bearing on the "Island Universe" Hypothesis

The relation of the spirals to the galactic system is not so easily disposed of as the cases considered above. In support or in partial support of the hypothesis that spirals are external stellar systems, arguments based on the following four points may be advanced:

(*a*) Distribution with respect to the galactic plane, assuming obstruction of light in and near the Milky Way.[3]

(*b*) High radial velocities.

(*c*) Certain spectral characteristics.

(*d*) Some evidences of great distance.

Less definite propositions that may be ranged on this side of the question are:

(*e*) Improbability of a single galactic system in the sidereal universe.

(*f*) Physical appearance of a few of the spirals.

(*g*) Resemblance of structure in spirals to hypothetical spiral structure of the Milky Way System.

In the light of recent studies of nebulae and the galactic system, the arguments founded on the seven foregoing points do not appear to establish the stellar interpretation; and none of them appears to be particularly troublesome for the hypothesis that the spiral nebulae are not external stellar systems. Many of these arguments, in fact, are better interpreted according to this alternative theory that spiral nebulae are truly nebular objects.

Five additional points, which are apparently of much weight and, taken together, seem decidedly unfavorable to the stellar interpretation of spirals, are as follows:

(*h*) New conception of the dimensions of the galactic system.

(*i*) Measures of internal motion in spiral nebulae.

(*j*) The occurrence of novae in spirals and their magnitudes at maximum.

(*k*) The systematic nature of the radial motions of spirals.

[3] *Cf.* Curtis, *loc. cit.*, p. 225.

(*l*) The probable dependence of their distribution on galactic position.

Some of the foregoing are not completely independent of each other.[4] Four further points of less weight that may be suggested as opposed to the "island universe" theory are:

(*m*) The possibility of formulating a fairly satisfactory nebular theory of the spirals.

(*n*) Directly measured parallaxes.[5]

(*o*) The data of proper motion relative to mean distances and drifts.

(*p*) The apparent absence of a central nucleus in the galactic system.

III. Remarks on the Principal Points Favoring the "Island Universe" Hypothesis

a and *l*. The well-known avoidance of low galactic latitude by spiral nebulae, and the progressive but irregular concentration to the galactic poles, is most naturally taken as evidence that the distribution of spirals and galactic stars is to a certain extent complementary; therefore, that the spirals are dependent and subordinate factors of the general system. It would be difficult indeed to believe that external and independent stellar "universes" could exhibit such striking relations to our particular stellar system when, in addition to this apparent dependence of distribution on galactic latitude, we also note: first, that the avoidance by spirals (particularly by the brighter ones) is greatest in the direction of the galactic center where the stars, globular clusters, planetary nebulae, etc., are most numerous, and that the avoidance is least in the northern hemisphere where the Milky Way is the thinnest and globular clusters are totally absent; and, second, that the radial velocities observed are not random, but have a definite relation to the galactic system and perhaps even depend on the angular distance from an apical point in or near the Milky Way.[6]

On the other hand, Campbell,[7] Curtis,[8] and others have proposed that spirals may actually be distributed at random, and that the apparent distribution with respect to the Galaxy can be explained

[4] For instance, the value of *j* may involve a partial acceptance of *h*.
[5] van Maanen, *Mt. Wilson Contr.*, No. 158, 1918.
[6] *Mt. Wilson Contr.*, No. 161, Section VII, 1918. *Cf.* also reference below to work by Wirtz.
[7] *Science, N. S.*, **45**, 531, 1917.
[8] *Loc. cit.*

by assuming that obstructing matter encircles the galactic discoid —dark occulting nebulosity analogous to that observed in the peripheral equatorial regions of many spiral nebulae. Patches of dark nebulosity certainly exist in the galactic system, at no great distance from the Sun, and it is quite possible that the apparent avoidance of the lowest latitudes by globular clusters is due to such material.[9] Spirals in the galactic plane beyond the confines of our system would be occulted as readily as globular clusters. In general, the observed distribution could be secured by liberal use of the hypothetical encircling opaque material.

The region avoided by spirals, however, particularly in the southern hemisphere, is many times wider than that avoided by globular clusters. A great area of the southern sky (well out of the Milky Way[10]) is quite transparent both to near and to extremely distant globular clusters, but it is practically devoid of spiral nebulae sufficiently bright to have been observed. We must conclude, it appears, either that the spirals, whether near or distant, do not exist in that direction, or that there is a most remarkable arrangement of obscuring patches that eliminates all spirals but leaves a normal distribution of globular clusters.[11]

b. A few years ago Slipher's discovery that spiral nebulae as a class have extraordinarily high radial velocities gave new life to the theory that these objects are distant stellar systems.[12] The average motion of the various types of stars and nebulae has been contrasted many times and the argument advanced that, since all galactic objects have reasonably small velocities, these peculiarly high values should therefore be attributed to separate "universes." During the last few years, however, this supposed isolation of the spirals has been altered. While their average radial velocity exceeds 500 km/sec, it is less than 400 km/sec for one-third of them. A number of galactic stars are now known with space velocities equal to or in excess of 400 km/sec. With the extension of the investigations of proper motion and radial velocity to the

[9]Shapley, *Proceedings of the National Academy of Sciences*, **5**, 344, 1919.

[10]Between galactic latitudes $+5°$ and $+25°$, $-5°$ and $-25°$.

[11]A third explanation that spirals, as compared with globular clusters, are very near to the solar system cannot be accepted in the face of other evidences of distance.

[12]That the large line-displacements in the spectra of spiral nebulae should be attributed to motion in the line of sight appears to be assured by a consideration of the following points: (1) The displacements are both positive and negative; (2) The appropriate relation of shift to wave-length is observed; (3) Orbital motions in eclipsing binaries occasionally show displacements of the same order of magnitude; (4) In linear velocity the rotation observed spectroscopically in some spirals approaches the velocity in the line of sight.

fainter magnitudes many high stellar velocities are being found.[13] Many globular clusters,[14] which are certainly subordinate to the galactic system, have radial velocities between 100 and 300 km/sec, and the great Magellanic clouds[15] also appear to have very high velocities of recession. Hence this argument of peculiarity in velocity seems no longer an important one for the "island universe" theory. High speed is not a condition impossible of production by the forces inherent in our galactic system.

c. The integrated and nuclear spectra of spirals are predominantly of a stellar type—usually resembling class G or K. With small dispersion the composite spectrum of a mixed group of stars, such as a globular cluster or a galactic system, would appear much the same. On the other hand bright lines are also found occasionally, and Seares's preliminary work on the distribution of color would indicate a much bluer spectral type for the nebular condensations in a spiral than for the nucleus.[16]

The analogy of the absorption spectrum of spirals with the composite spectrum of a stellar system cannot be carried very far, however, until higher dispersion has been used. We should remember that for many years stars differing so enormously in density, volume, and mass as the giant and dwarf eclipsing binaries of type G were classed together without question. Sidereal bodies in extremely different physical states obviously may give closely comparable spectra on the small dispersion that has been used for spiral nebulae.

d and *f*. With one or two possible exceptions the secondary nuclei in spiral nebulae are so distinctly nebulous that they cannot be considered individual stars. Even in Messier 33, probably the most conspicuously nucleated of the brighter spirals, it is easy on large-scale plates to distinguish between the superposed stellar images and the "softer" nebular condensations. It is possible, however, to see a resemblance of these diffuse nebulous objects to extremely distant stellar clusters,[17] but unless we introduce further unverified assumptions the analogy breaks down when the observed colors are intercompared.

[13]Adams and Joy, *Mt. Wilson Contr.*, No. 163, 1919; *cf.* Wolf's frequent notes on large proper motions in recent volumes of the *Astronomische Nachrichten*.
[14]*Mt. Wilson Contr.*, No. 157, p. 12, 1918.
[15]R. E. Wilson, *Proc. Nat. Acad. Sci.*, **1**, 183, 1915.
[16]*Mt. Wilson Communication*, No. 36, 1916.
[17]*Publications Astr. Soc. Pac.*, **29**, 217, 1917.

IV. Evidence Unfavorable to the "Island Universe" Hypothesis

The observational and theoretical evidence against the stellar interpretation of spiral nebulae has already been discussed in various earlier papers on clusters;[18] in the present article space will be taken for only a brief summary of the arguments.

h. Formerly we compared any hypothetical external galaxy with a stellar system supposedly about 10,000 or 20,000 light-years in diameter. Recent studies of the galactic system indicate that its greatest diameter is not less than 300,000 light-years. This newer conception greatly embarrasses the interpretation of spirals as stellar organizations of a size comparable to that of the Galaxy. To be linearly as great as this, tho angularly small, demands a distance from the Earth, even for the spirals of largest angular size, that would completely discredit many observational results. For example, if any bright spiral of 10′ greatest apparent diameter has an actual diameter directly comparable with that of the galactic system, its distance must be greater than a hundred million light-years.

i. Under such circumstances the measures of internal motion by van Maanen, Kostinsky, and Lampland, would need to be summarily rejected. For instance, van Maanen's[19] careful measures of the nebulous points in Messier 101 would indicate rotational velocities greater than the velocity of light if that spiral is held to be even one-fifth as large as our Galaxy now appears to be. Similarly, the systematic drift derived by Wirtz[20] from a study of several hundred spirals, and the average proper motions suggested by the studies of Wirtz and Curtis[21] would indicate appalling velocities in space—quite irreconcilable with the spectroscopically measured velocities of translation and rotation.

j. Moreover, if in real dimensions spiral nebulae were analogous to our galactic system, the absolute magnitude of the novae in spirals would far transcend any luminosity with which we are acquainted, and would be at direct variance with present results

[18] *Ibid.*, **30**, 42, 1918; *Mt. Wilson Contr.*, No. 157, p. 1, 1918, and No. 161, Sections VII and VIII, 1918.

[19] *Mt. Wilson Contr.*, No. 118, 1916.

[20] *Astronomische Nachrichten*, **203**, 197, 293, 1916; **204**, 23, 1917; **206**, 109, 1918.

[21] *Pub. Ast. Soc. Pac.*, **27**, 217, 1915. In subsequent references Curtis has stated his lack of confidence in the reality of the observed proper motions, *Jour. Wash. Acad. Sci.*, **9**, 221, 1919. The average time interval between first and second observations is 13 years and 40 years respectively, in the investigations by Curtis and by Wirtz.

on intrinsic stellar brightness. For at the distance computed above the absolute magnitude of a nova of the sixteenth apparent magnitude would be -16, nearly two hundred thousand times as bright as the novae of the galactic system for which van Maanen has determined the absolute luminosities.[22] An upper limit to the intrinsic brightness attainable by stars is suggested by recent observational and theoretical work, and this limit is much fainter than -16. The study of globular clusters, for example, has yielded sufficient knowledge of the luminosity of more than a million stars to show that not one is within ten magnitudes of this enormous brightness. The luminosity of about 2000 stars of the solar environs is now known, and probably none is even a ten-thousandth as luminous as absolute magnitude -16. Hence stellar luminosities of this order seem out of the question, and accordingly the close comparability of spirals containing such novae to our Galaxy appears inadmissible.

Let us abandon the comparison with the Galaxy and assume an average distance for the brighter spirals[23] that will give a reasonable maximum absolute magnitude for the novae. Then the measured internal motions also become reasonable and in good agreement with spectroscopically determined rotational velocities; likewise the distances become reconcilable with the data from proper motion.

The simple hypothesis[24] that the novae in spirals represent the running down of ordinary galactic stars by the rapidly moving nebulosity becomes a possibility on this basis of distance, for the brighter spirals are within the edges of the galactic system. Further, it is possible to explain the peculiar distribution of spirals and their systematic recession by supposing them repelled in some manner from the galactic system, which appears to move as a whole thru a nebular field of indefinite extent.[25] But the possibility of these hypotheses is of course not proposed as competent evidence against the "island universe" theory.

[22] *Cf. Pub. Ast. Soc. Pac.*, **31**, 234, 1919.

[23] Provisionally, let us say, of the order of 20,000 light-years. If novae in spirals attain apparent magnitude 16, certainly bright stars, if present, should be easily photographed, and the failure to resolve the brightest spirals indicates that they are not composed of typical stars. (*Cf.* a suggestion on the origin and constitution of spiral nebulae, *Mt. Wilson Contr.*, No. 161, p. 29, and also the mathematical theory by Jeans, *Monthly Notices*, **77**, 186, 1917). At a distance of 20,000 light-years, if there were ordinary stars of absolute magnitudes between 0 and $+5$, they would appear of magnitudes 14 to 19, and therefore conspicuous on ordinary photographs. Even if 200,000 light-years distant, the giant stars would be easily resolved on existing photographs.

[24] *Pub. Ast. Soc. Pac.*, **30**, 53, 1919.

[25] *Mt. Wilson Contr.*, No. 161, Sections VII and VIII, 1918.

V. Conclusions

Observation and discussion of the radial velocities, internal motions, and distribution of spiral nebulae, of the real and apparent brightness of novae, of the maximum luminosity of galactic and cluster stars, and finally of the dimensions of our own galactic system, all seem definitely to oppose the "island universe" hypothesis of the spiral nebulae. Data relating to proper motion are also in better harmony with the hypothesis that spiral nebulae are not stellar systems. The evidence now supporting the "island universe" interpretation appears unconvincing, for many of the best arguments formerly proposed on that side of the question have been invalidated or much weakened by recent research. We have, however, no evidence that somewhere in space there are not other galaxies; we can only conclude that the most distant sidereal organizations now recognized—globular clusters, Magellanic clouds, spiral nebulae—cannot successfully maintain their claims to galactic structure and dimensions.